

Real-time Leaky Lamb Wave Spectrum Measurements and its Application to NDE of Composites

Shyh-Shiuh Lih and Yoseph Bar-Cohen

Jet Propulsion Laboratory, Caltech, MS 158-103, 4800 Oak Grove Dr., Pasadena, CA
91109-8099, 818-354-0784, fax 818-354-0998, lih@jpl.nasa.gov

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Challenges to NDE of composites

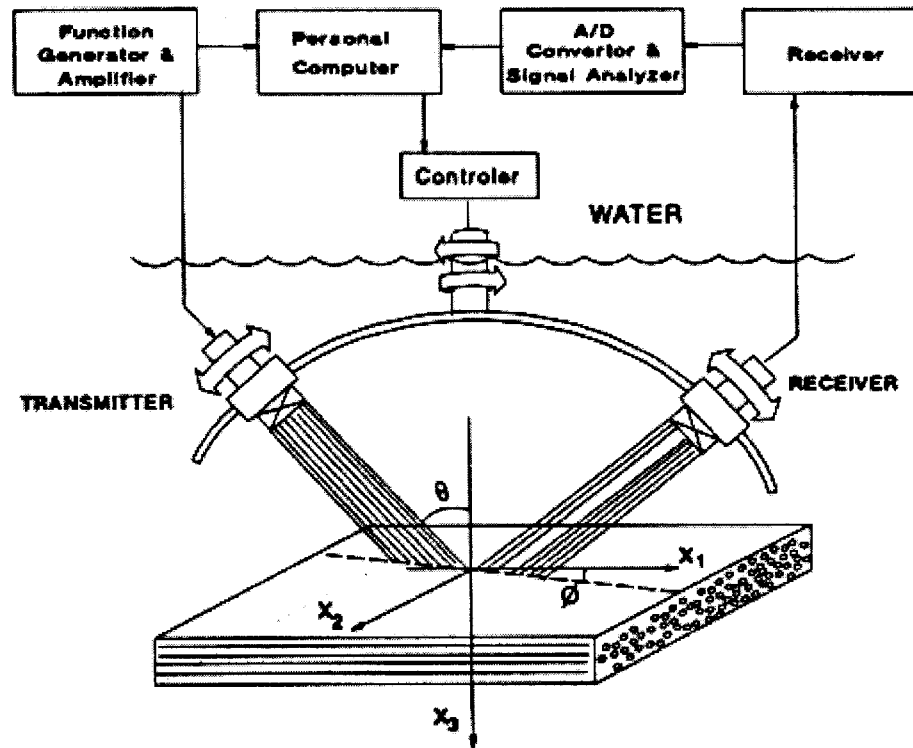
- Defect Detection and Characterization
- Characterization of Material Properties
- Rapid Large Area Inspection
- Real-Time Health Monitoring
- Smart Structures
- Residual Stresses
- Weathering and Corrosion Damage

Ultrasonic Leaky Lamb Waves (LLW)

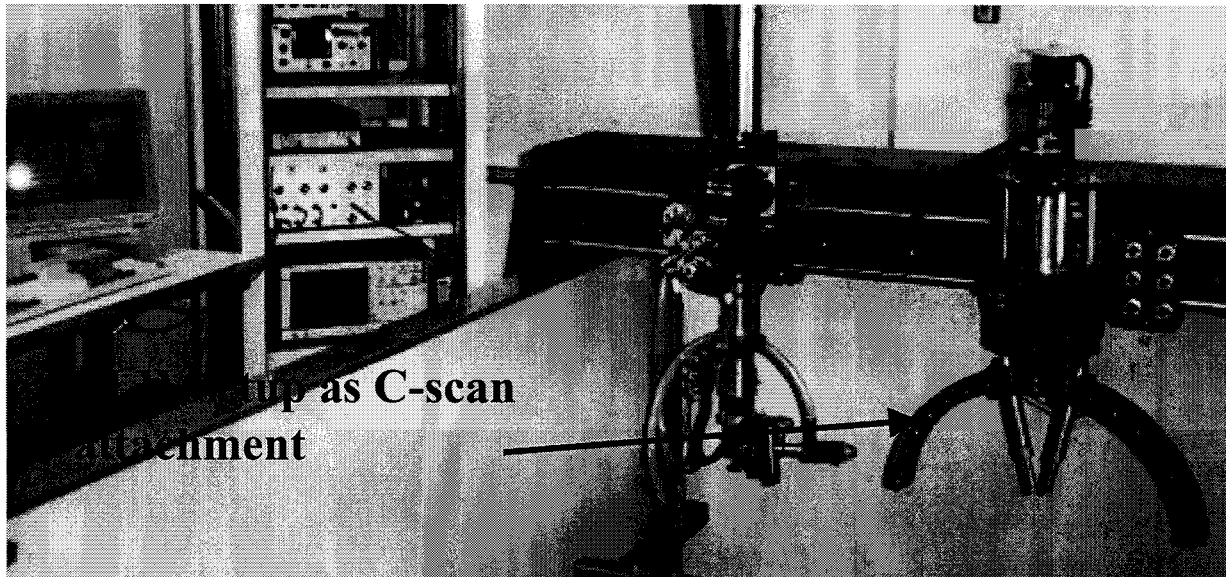
- Phenomenon in composite materials was discovered by Y. Bar-Cohen in Aug. 1982
- Very good agreement was shown between theoretical analysis and experimental data
- An efficient and rapid data acquisition setup was developed
- An inversion algorithm was developed to determine the elastic constants
- Method was applied to defects imaging and characterization

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Leaky Lamb Waves (LLW) Experimental Setup



Leaky Lamb Wave (LLW) Test System



E_{11} (GPa)	157.7700
E_{22} (GPa)	10.8200
G_{12} (GPa)	7.9820
G_{23} (GPa)	3.6367
ν_{12}	0.3374
ρ (gm/cc)	1.5780
C_{11} (GPa)	162.7290
C_{22} (GPa)	14.5270
C_{12} (GPa)	7.3590
C_{23} (GPa)	7.2500
C_{55} (GPa)	7.9820

Areas of concern associated with applying LLW

Complex acquisition and processing of the data

- Improve the data acquisition process
- User friendly software

Assumed material density

- Inverted material constants are based on assumed data
- Density can be measurement by radiography but it is not practical.
- An alternative single side real-time NDE method is needed
- Preferred use of ultrasonics to minimize instrumentation complexity

Complex and ill-posed lamina-base analysis

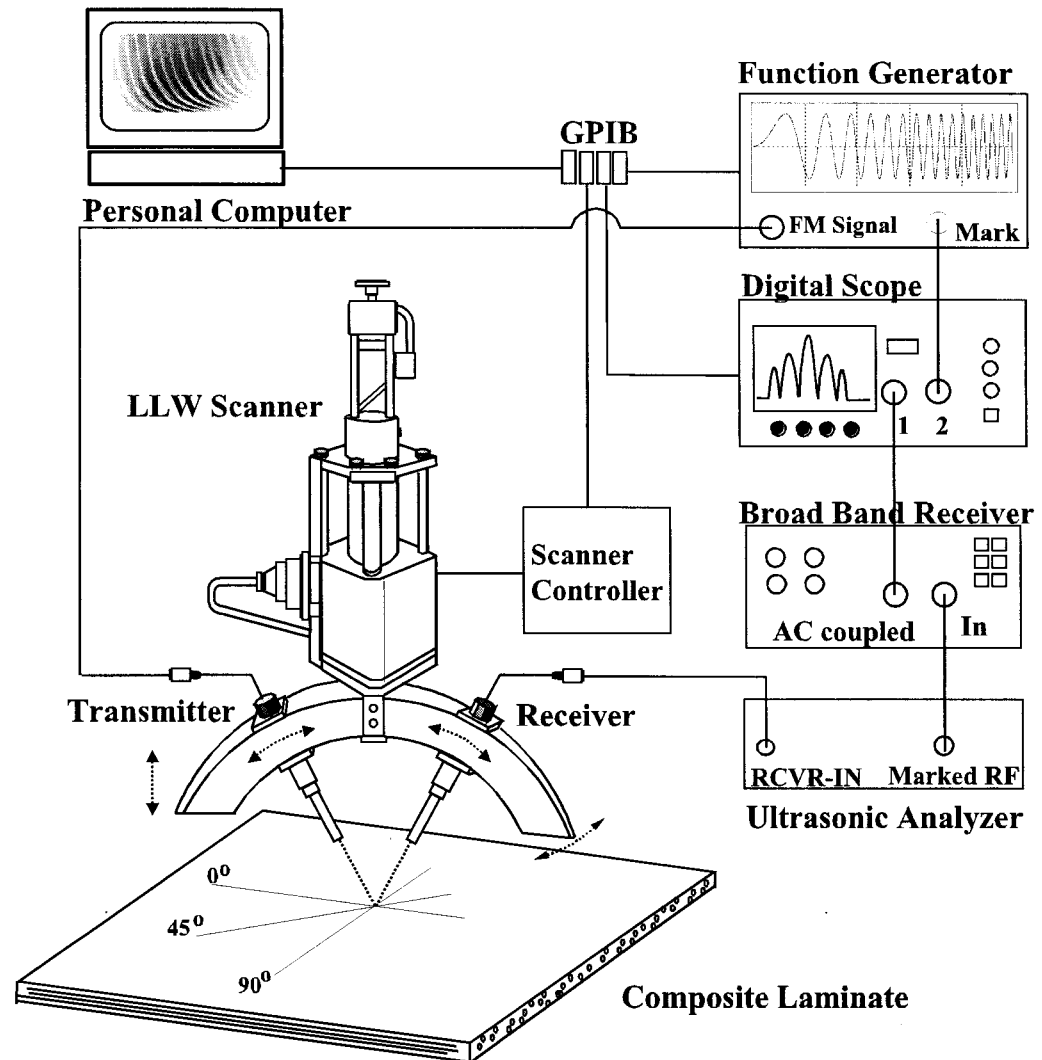
- The inversion algorithm for elastic properties was successful for unidirectional laminates.
- Analysis of multi-orientation layers using lamina modeling is complex and ill-posed
- Currently we are studying inversion methods that don't require lamina-base analysis

Time-consuming process

- Spectral acquisition of LLW data thru sweeping individual frequencies is time consuming and can take about 10 and 20 minutes.
- Modifications of the JPL scanner requires now <1-min for 20 angles of incidence.

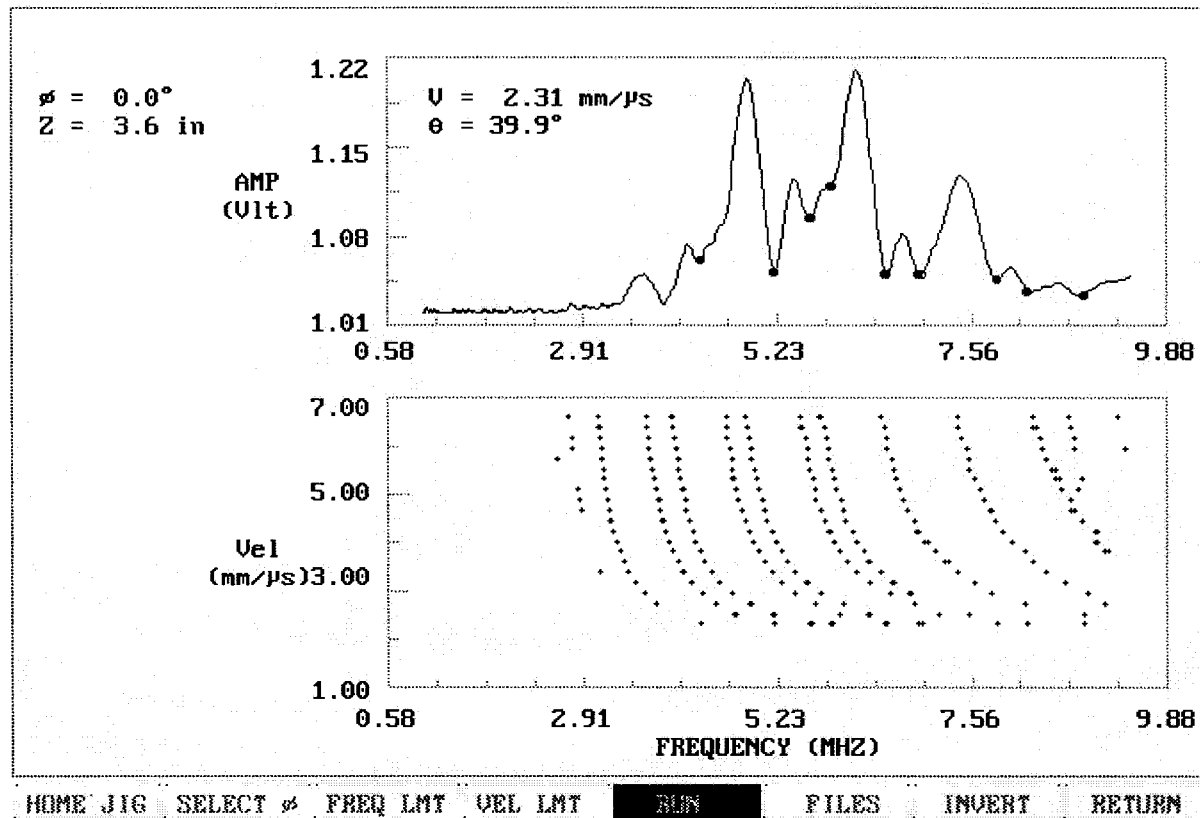
LLW scanner and test system

The LLW scanner is computer controlled and the dispersion data can be obtained rapidly

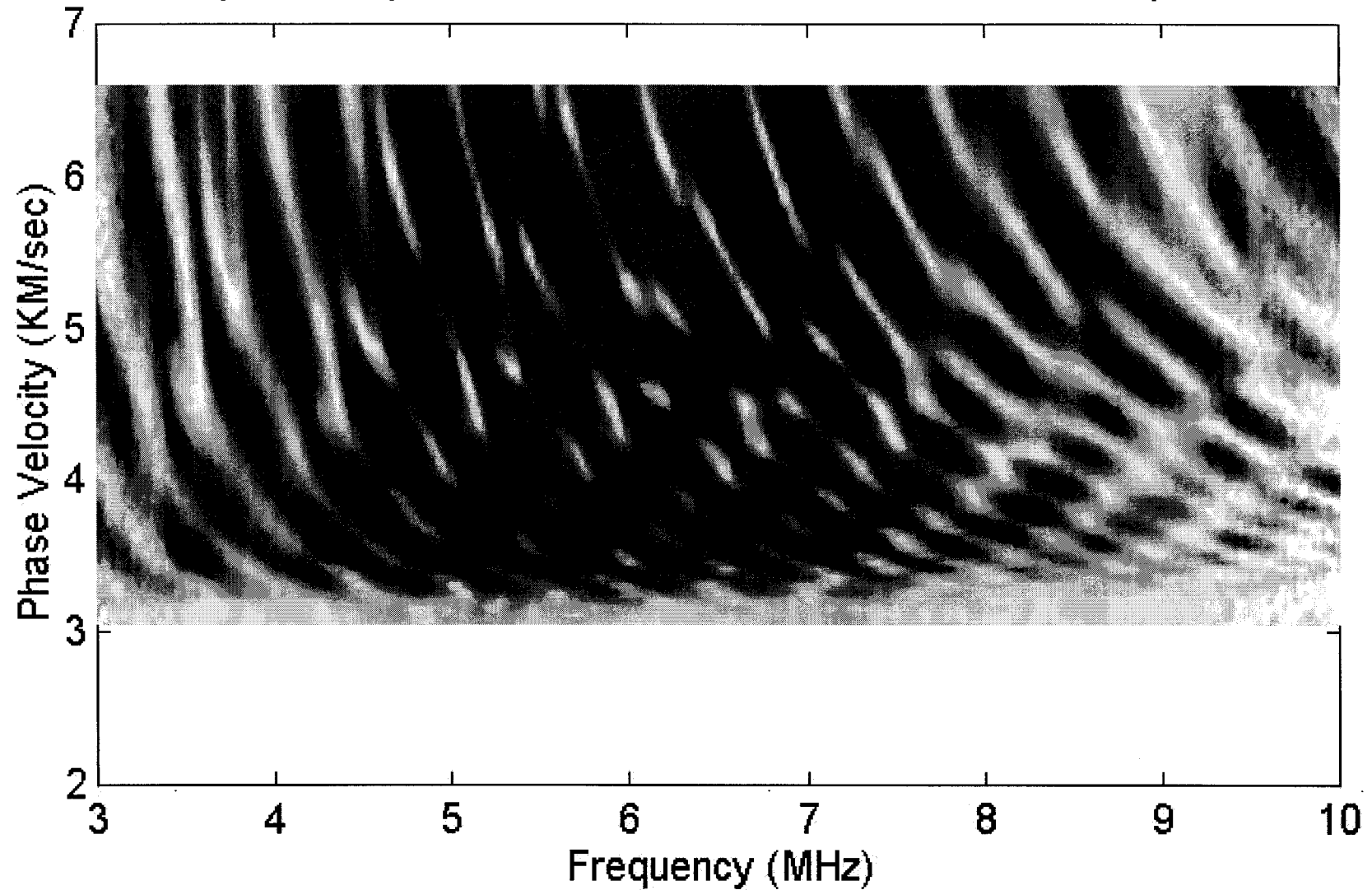


Dispersion data for porosity

Middle layer of $[0]_{24}$ Gr/Ep laminate



Dispersion Spectrum of a 3.125 mm Unidirectional Composite (90 Deg.)



Rapid LLW dispersion data acquisition

- The LLW experimental setup was recently enhanced to speed the data acquisition and increase the number of modes that can be identified in a LLW experiment
- The transmitted signals were modified to FM modulated pulses that are induced sequentially within the required spectral range.

The specific signal consisted of a time-dependent voltage function $V(t)$ that is amplified and transmitted at an induced frequency $f(t)$

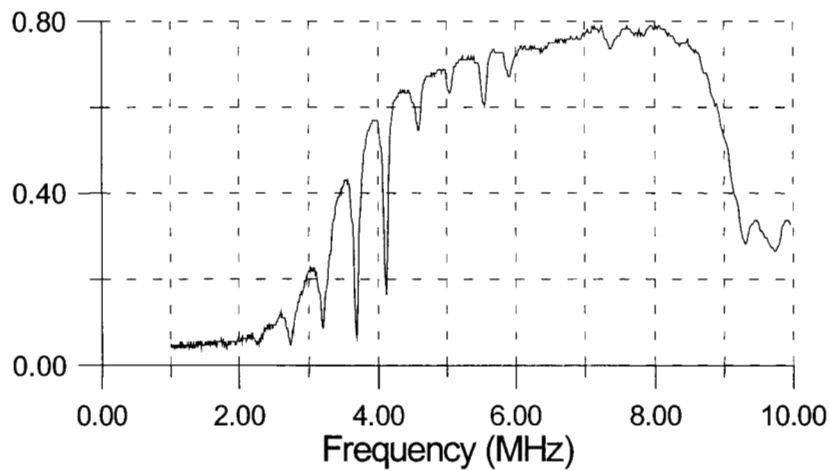
$$f(t) = f_0 \times (1 + k_1)^{tk_2}$$

where f_0 is initial frequency and the constants k_1, k_2 are the frequency parameters related to time for sampling.

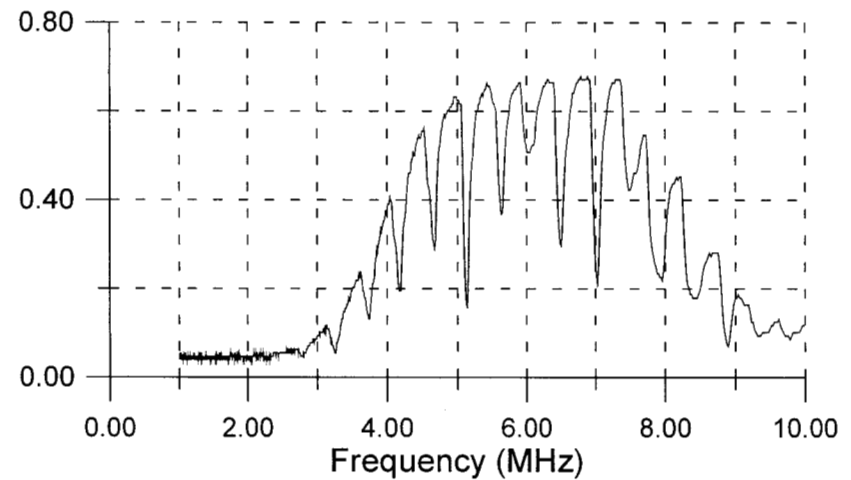
Rapid LLW dispersion data acquisition (Cont.)

- The trigger is based on the selected time frame
 - It is transmitted to synchronize the reflected signals on the data acquisition scope
 - The time domain signal is converted to spectral data using the driving function
 - The function generator provides a reference frequency marker for the calibration of the acquired data
- The reflected spectra for each of the desired angles of incidence is displayed on the monitor
 - The locations of the minima (LLW modes) are marked by the computer on the reflection spectrum
 - The minima identification algorithm was modified to reliably use smaller signals, which are associated with more diffused modes.
 - The identified minima are accumulated on the dispersion curve
 - An image processing procedure was used to display the dispersion curves.

High adjustment algorithm

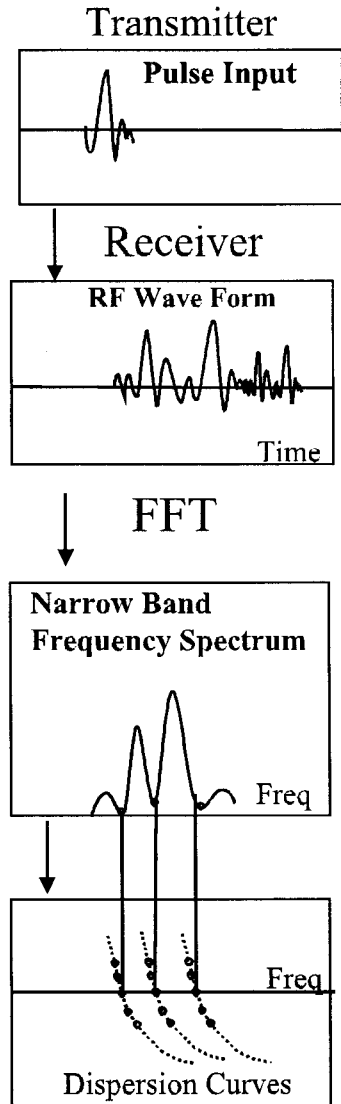


"Out of focus" LLW reflection spectrum.

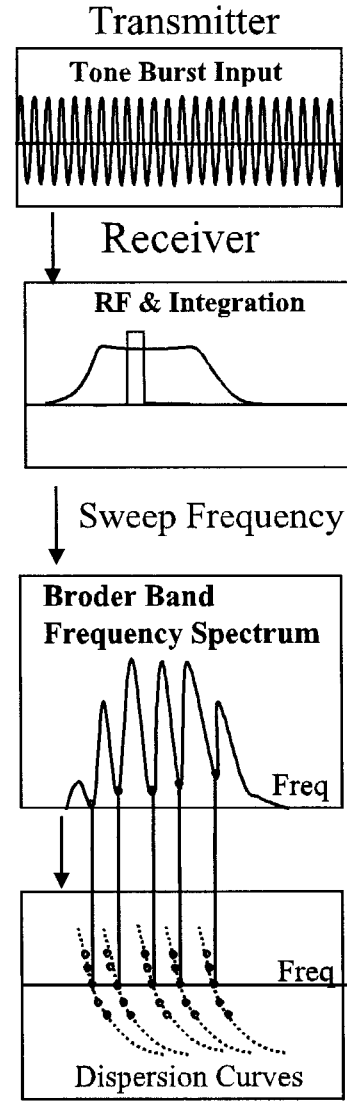


Optimized reflection spectrum using adaptively adjusted transducers pair height.

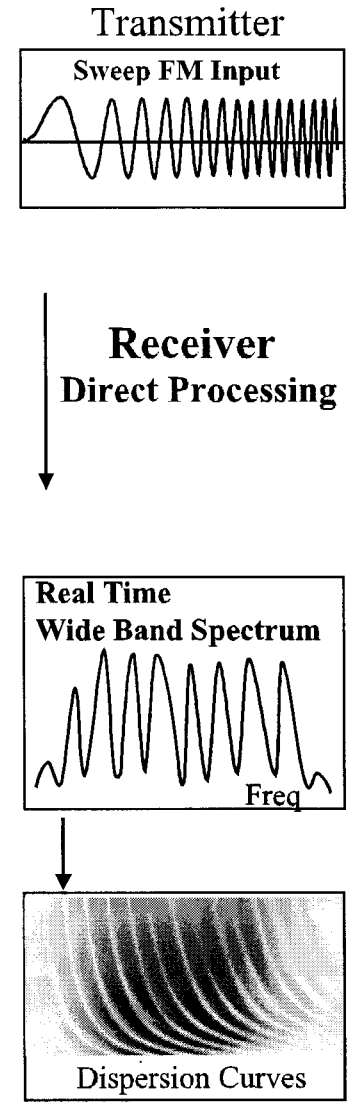
LLW Evolution - Summary



Prior Method 1



Prior Method 2



Current Method

Concluding remarks

- LLW measurements allow rapid assessment of material properties.
- The test setup was enhanced to the level that allow acquisition of diffused modes that otherwise would have been considered noise.
- The recent enhancement of dispersion curves acquisition speed makes the characterization of defects using LLW an effective NDE tool
- Challenges are still hampering the transition of the LLW method to practical use.
- Future development in density measurement accessing from a single side and improvement in inversion of multi-layered composites will help address these challenges